MASTER

Westinghouse

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From: Reactor Analysis

Subject: Thermal Stress Considerations in Fuel Cluster Support Component.

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The practical aim of investigation of thermal stresses in the component supporting a cluster of six fuel elements, is to establish the limiting conditions imposed by component yielding due to severe thermal gradients.

This memorandum is written with the purpose of presenting a brief discussion of the stresses arising in the support element and proposing a program of investigation.

It is desirable to use an idealized analysis which involves only the most significant parameters so that the results may afford the maximum insight, without including secondary effects which are at the same time of secondary importance. However, it should be emphasized that even though the idealization might be reasonable, the results of analysis should be checked with experimental values.

The problem is then to determine the temperature distribution within the support element, under stipulated steady and unsteady state conditions, then

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calculate the thermal stresses induced by these gradients. Needless to say, the maximum stresses should be obtained by superposition of thermal stresses and the stresses due to loading.

Two cases may be considered and solved in the following order:

1. The simpler case of axially symmetric temperature distribution in the support element.

2. The case of non-symmetric temperature fields. This is encountered when one or more of the elements supported overheats or underheats relative to the remaining elements. The reason for overheating may be non-proportionate gas flow distribution to the coolant passages or inexact loading of the fuel.

With reference to the problem of temperature distribution, it seems plausible to consider the heat flow in the support components as two dimensional. In the case of symmetry, it would suffice to consider only a segment. In the case of non-symmetric heating, the temperature field and history should be determined and examined under combined conditions of overheating or underheating of one, two or three elem ents of a cluster. This trial procedure is proposed because of the difficulty of judging - a priori - the mode of overheating causing the maximum temperature gradients and hence the maximum thermal stresses which occur in the supporting element without actually carrying out the computation.

One important aspect in the stress analysis which should not be neglected is the stress concentration due to the corners in the hexagonal geometry as well as the corners in the central hole at points of change of diameter.

From the standpoint of thermal stress study, the simplest case to which the support element can be reduced is that of a solid thin circular disc or a circular cylinder when an axially symmetric two dimensional temperature field exits in them. By application of the elastic theory it can be shown that the stresses are expressible as follows:*

1 - The thin circular disc

If the outer radius of the disc is "b" and the radius of the concentric hole is "a"

$$\sigma_r = \alpha E \left[\frac{1}{b^2} \int_0^b T r \, dr - \frac{1}{r^2} \int_0^r T r \, dr \right]$$

$$\sigma_\theta = \alpha E \left[-T + \frac{1}{b^2} \int_0^b T r \, dr + \frac{1}{r^2} \int_0^r T r \, dr \right]$$

2 - The cylinder with a concentric circular hole

$$\sigma_r = \frac{\alpha E}{1 - \gamma} \frac{1}{r^2} \left[\frac{r^2 - a^2}{b^2 - a^2} \int_a^b T r \, dr - \int_a^r T r \, dr \right]$$

$$\sigma_\theta = \frac{\alpha E}{1 - \gamma} \frac{1}{r^2} \left[\frac{r^2 + a^2}{b^2 - a^2} \int_a^b T r \, dr + \int_a^r T r \, dr - T r^2 \right]$$

$$\sigma_z = \frac{\alpha E}{1 - \gamma} \left[\frac{2}{b^2 - a^2} \int_a^b T r \, dr - T \right]$$

In the case of a steady state heat flow, if the temperature on the inner surface is T_i and on the outer surface is zero, the temperature T at

*Theory of Elasticity, S. Timoshenko and J. N. Goodier, McGraw-Hill, 1951 any distance r from the center is represented by the expression

$$T = \left[T_i \Big/ \log\left(\frac{b}{a}\right) \right] \log \frac{b}{r}$$

The outer surface does not need to be at zero temperature for this solution to apply. If the temperature on the outer surface is T_o then T_i should be taken as the difference between the outer and inner temperatures and may be positive or negative. However, the level of temperature should be taken into account for evaluation of yeild stress.

The thermal stresses in this case will be

$$\sigma_r = \frac{\alpha E T_i}{2(1-\gamma)\log\left(\frac{b}{a}\right)}\left[-\log\frac{b}{r} - \frac{a^2}{b^2-a^2}\left(1-\frac{b^2}{r^2}\right)\log\frac{b}{a}\right]$$

$$\sigma_\theta = \frac{\alpha E T_i}{2(1-\gamma)\log\left(\frac{b}{a}\right)}\left[1-\log\frac{b}{r} - \frac{a^2}{b^2-a^2}\left(1+\frac{b^2}{r^2}\right)\log\frac{b}{a}\right]$$

$$\sigma_z = \frac{\alpha E T_i}{2(1-\gamma)\log\left(\frac{b}{a}\right)}\left[1-2\log\frac{b}{r} - \frac{2a^2}{b^2-a^2}\log\frac{b}{a}\right]$$

*A list of symbols is attached.

These equations are directly applicable to cylindrical parts subjected to severe temperature gradients such as the pyrolitic graphite liner in the central hole of the fuel cluster support element.

Tentative Procedure

It appears most expedient to obtain the steady state two-dimensional temperature fields by means of the available conducting analog.

The "TOSS" code available now is suited for the transient temperature calculations as well as three dimensional considerations.

Temperature fields generated by reactor Analysis will be communicated to the Mechanical Group, for cooperation in stress calculations to determine the maximum stresses in each case due to thermal gradients and loading.

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LIST OF SYMBOLS

σ_r	=	the radial stress at a radius r
α	=	the coefficient of thermal expansion
E	=	Young's modulus of elasticity
a	=	the inner radius of the concentric hole
b	=	the outer radius of the disc or cylinder
T	=	the temperature at a radius r
ν	=	Poisson's ratio
σ_θ	=	the tangential stress at r
σ_z	=	axial stress at r.